TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909

INCORPORATED 1930

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VOLUME XVIII
No. 2 — 1953

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

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Visual Fatigue

With Special Reference to Lighting

By H. C. WESTON *(Fellow)*

Summary

"Visual fatigue" is often mentioned in discussions on the effects of different systems of lighting. Because the state so-named is not well understood, the nature and extent of the activities involved in seeing are examined to find a basis for it. Retinal fatigue—if it occurs at all—gives no feeling of "visual fatigue." But vision is essentially a motor as well as a sensory process. Numerous muscles are *necessarily* at work for seeing; the action of others—of the face, head and neck—is common and helpful, and the whole voluntary neuro-muscular system of the body participates in acts of the most intent vision. From excessive muscular—though not exclusively oculo-muscular—exertion and from "mental exertion" comes so-called "visual fatigue." Such exertion may be due to unsuitable lighting, to "unphysiological" visual tasks or to ocular defects. Some relevant visual posture and time studies are described, and also, a study of facial muscular reactions to glare. Boredom and sleepiness due to lighting are distinguished from fatigue, and a definition is offered of "visual fatigue" in terms of the common meaning of "fatigue."

This paper has two related aims: first to discuss the application of the common notion of fatigue to the visual organism and then, on this basis, to consider under what conditions of lighting "visual fatigue" is most likely to occur.

(1) Definitions of Fatigue

The expression "visual fatigue" is gaining currency in the literature of lighting, in spite of the fact that its meaning has never been defined satisfactorily, although sporadic but serious attempts have been made to say what it should be used to mean. This may seem strange, since what is commonly called "fatigue" is one of the most general of experiences. On the one hand, it has been said that the word "fatigue" is so familiar and intelligible that it is unnecessary to define it (Külpé, 1895)(1), and on the other, that it can mean so many things that a definition is essential (Adrian, 1928)(2). Indeed, because the word can mean, and has been used to mean, so many things, one of the author's colleagues (Muscio, 1921)(3) suggested more than 30 years ago that it should not be used at all in scientific discussions. A number of the formal definitions of fatigue have been discussed quite recently by Carmichael and Dearborn (1947)(4).

In ordinary language "fatigue" means "weariness resulting from bodily or mental exertion"(5). Almost invariably it seems now to be regarded as undesirable, though nineteenth-century writers on the subject thought it so only when carried to excess. In ordinary degrees, fatigue was classed as one of the pleasurable experiences allied to the muscular system (Bain, 1855)(6), and "the beneficial, but not exhausting, fatigue of the nerves" was spoken of as underlying the feeling of comfort (Helmholtz, c. 1871)(7). At least one contemporary writer on the subject (Smith, 1943)(8) has pointed out that it should not be thought—as so very often it is—that fatigue is an unmitigated evil.

In these references to fatigue, precedence is given to the quality of feeling connected with the particular organic condition, and it is a feeling recognised as pleasantly or unpleasantly toned according to its intensity. In modern technical definitions of general fatigue, on the other hand, whether formulated by psychologists or by physiologists, the emphasis is upon the objective rather than the subjective aspect.

The author is Director of the Group for Research in Occupational Optics, Medical Research Council. The manuscript of the paper was received on October 30, 1952. The paper was presented at a meeting of the Society held in London on December 9, 1952.

By way of example, Scripture wrote in 1897: "Fatigue is defined as the decrease in the capacity for work; fatigue in this sense may or may not have definite relations to the peculiar sensation known as 'the feeling of fatigue.'"(9)

More recent definitions have a similar meaning. (Health of Munition Workers Committee, 1917(10); Adrian, 1928(11); Drever, 1952(12); Bartlett, 1952(13).)

(2) Exertion in Vision

If these definitions are accepted as covering the conception of fatigue in general, then it is to vision considered as work, and not as "seens" or perceptions, that visual fatigue must be due. Certainly vision involves bodily and mental exertion but, so long as all goes well, there is little awareness of, and little interest in, those of its organs which are incessantly, and necessarily, moved by muscular effort. Its indispensable motor character is not indicated at all by the classification of vision as one of the popularly enumerated five special senses. In fact, all these senses are, so to speak, motorised and, most obviously, those of touch and vision.

Sensations of light and colour are the "stuff" of vision, and they are "all that is properly perceived by the visive faculty" (Berkeley)(14) conceived as purely sensory. But, this "stuff" must first be got and then "made-up" before what is ordinarily and rightly understood by seeing is accompliished. The getting is not done by stationary crowds of receptors posted behind two windows in the face, but by crowds housed in rotatable fenestrated orbs so that they can be turned as a body, this way and that, in search of the "stuff" of vision. Nor is this all the movement in vision; there is more that is either necessary or helpful, and this latter has much more to do with so-called "visual fatigue" than is generally realised. The "making-up" is the task of the brain. It is an activity of some sort, although little is known of it beyond the fact that it seems to involve little expenditure of energy by comparison with that in muscular activity. Nevertheless, here is the physical correlate of the mental exertion which visual perception entails. There is always some such exertion, for every filling of the visual field to which attention is given poses questions of identity to the mind, and every act of visual cognition is a worked solution of a problem of this kind. More often than not, the problems are very easy ones if the sight is normal and sufficient experience has been acquired, and the end-product—the visual perception—comes without any awareness of mental effort in getting it, and without, indeed, any thought or explicit feeling of the active neuro-muscular mechanism. In adverse conditions, such as fog or dim lighting, seeing is accompanied by feelings of effort, strain and ultimately of fatigue which, for the most part, are referred to the region of the muscular parts acting in vision, which are, indeed, acutely tensed. Again, in the prolonged scutiny of minute detail it is the visual muscles which are the most obvious doers of work, and it is the muscled eyes that are said to be tired by such a visual task.

(3) Sensations from Retinal Stimulation

There are many references in the literature to fatigue of the retina. Such a condition used to be described in the text-books of ophthalmology under the name "retinal asthenopia" (literally: *asthenopia*=weakness of sight). It was said to be a state of "exhaustion of the retinal sensibility induced by prolonged visual effort" (Clarke, 1892)(15), or by "long hours of near work which has been done by artificial light" (Hartridge, G., 1900)(16).

Its symptoms were paradoxical. Sometimes the acuity of vision was diminished, but it might be very good. There was photophobia, attributed to retinal hyperaesthesia, although if the retinal sensibility was exhausted there should be no intolerance of light but a diminution of light sense. It could be produced not only by bright lighting—in which, as is now known, the "rate of working" of the retina is relatively high—

but also by "ordinary" lighting, as well as by candlelight. It was generally agreed that so-called retinal asthenopia occurred almost exclusively in persons whose "nervous system is exceedingly sensitive and unstable," that is, in persons of the hysterical or neurasthenic type. No wonder that it was "always troublesome and difficult to cure" (Hartridge, G., loc. cit.).

Whether true (functional) fatigue of the retina actually occurs as a result of its own day-long activity is uncertain. If it does, it will very likely be accompanied and masked by fatigue of the visual muscles; it is unlikely that it would appear subjectively as a feeling of fatigue rather than one of declining image luminosity. It has been pointed out (Parsons, 1927, 1943)[17] that some, at least, of the phenomena of muscular fatigue appear to be due to the accumulated chemical products of metabolism, whereas the chemical changes which occur when the retina is stimulated are reversible, so that, with physiological intensities of excitation, functional fatigue either does not occur or is very transient. "Eyestrain undoubtedly occurs, but there is no evidence to show that it is due to retinal fatigue."

Nevertheless, the retina is not a simple mass of independent receptors but a complex organ having the anatomical features of a nervous centre, and which is the seat of nervous interaction. So, as Adrian[18] has conceded, true fatigue of the retina may not be impossible. The difficulty of its appearance as *feeling*, however, remains. Although there is increased "subjectivity in the eye" (Feuchtersleben, 1847)[19]—i.e., awareness of the sense-organ itself*—when "visual fatigue" is complained of, it is not from the state of the retina itself that this arises. Stimulation of the retina, whether normally by light or abnormally by a blow or pressure, gives rise to visual sensations and, as far as is known, to sensations of no other kind. In no circumstances can visual sensations become other-sensations, or even sensations of mixed type, such as luminosity-strain or luminosity-fatigue sensations. Even pathological states of the retina excite no feeling, so that their victims may notice only a general failing of sight, or a contraction of the visual field. A fatigued retina would, presumably, yield weak sensations of luminosity, or faint vision that, for all the subject may know, might as well be the result of weak stimuli as of retinal fatigue.

(4) The Visual Muscles

Feelings of fatigue or tiredness are the prompters of complaints of visual fatigue, and their basis must be sought elsewhere. As mentioned already, it is the activity of the various muscles used that appears to involve much of the energy expended in seeing. The non-visual sensory impressions derived from these muscles, from the eyeball itself (sensations of pressure or tension), and from tissues which are stretched or moved in the course of vision, seem to provide the sensory basis of the localised feeling expressed as "tiredness of the eyes," while, together with even more indefinite organic sensations—seemingly related to cerebral activity—they underlie the more diffuse feeling expressed as one of "visual fatigue." Hence attention needs to be directed particularly to the extent of the muscular activity involved in vision, especially in those circumstances which most often lead to complaints of visual fatigue.

In binocular vision no less than twelve muscles—six per eye—are involved in every movement and act of fixation of the eyes. These extra-ocular muscles are shown in Fig. 1. Four other muscles—two inside each eye—control the aperture of the eyes; these are the pupil constrictor and dilator muscles. Another two muscles adjust the curvature of the lenses according to the distance of the objects of regard, and another four muscles—two pairs—act to open and blink the lids of each eye. These twenty-two muscles in all are the strictly visual muscles. Though some of them act reflexly—

* "Let a man only fix his attention for a time on one of his own organs, especially one near the brain, as for instance, the eye, he will soon perceive the effect of thus fixing his thoughts, as an obscure sensation, in the organ itself. . . . Gazing too intently increases the subjectivity in the eye, even to pain, and thus hinders the objective perception."

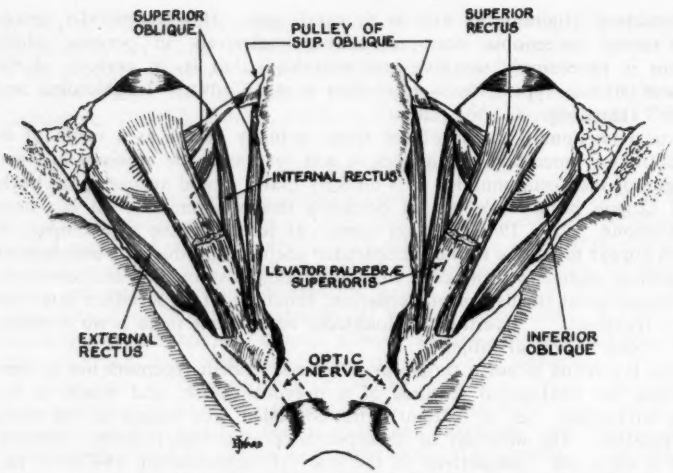

Fig. 1. The muscles which turn the eyes.

that is, involuntarily—at least sixteen of them are subject to voluntary control. They work not as independent units but in groups with delicately co-ordinated actions.

It is easy enough quickly to produce at will a feeling of strain and discomfort by action of the ocular muscles. Thus, an extreme conjugate movement of the eyes to the right or the left is so "fatiguing" that it soon becomes intolerable, and the unpleasant feeling lingers after the posture of the eyes has been changed. The feeling is elicited just as well if the lids are closed, so that any retinal contribution to it is ruled out. It is not wholly of muscular origin, for such a movement entails pressures and tensions of other tissues adjacent to the eyes. Similarly, if the eyes are converged to the near point of binocular single vision, a feeling of fatigue and a strong desire to relax the effort is not long in developing.

(5) Fatigue of Convergence and Accommodation

Two forms of fatigue occasioned by vision are recognised in ophthalmology, and both have to do with the eye muscles. The first form is fatigue of convergence. This can occur only in persons capable of binocular single vision, since it is just for this capacity that convergence is required. In orthophoric persons—that is, those having physiologically balanced oculo-motor apparatus—it does not occur unless protracted use is made of the eyes at very short range, or there is general fatigue which the ocular muscles will share. No kind of lighting will lead to fatigue of convergence in a situation which calls for little convergence, as when the only objects to which attention need be given are necessarily viewed from a distance of several feet; this is not to say, however, that fatigue of the extra-ocular muscles does not occur for other reasons in far vision. But when near objects have to be seen for considerable periods, inadequate lighting may cause them to be viewed from too close a distance and this will increase the liability to fatigue of convergence. Inadequate illumination will make the viewing distance required for visual resolution shorter than it otherwise could be, although this is not the only defect of lighting that will tend to do so. No kind of lighting will suffice to prevent convergence fatigue in those who do very fine work, and there must be suitable rest pauses, or the degree of convergence used must be kept down by wearing prismatic spectacles (Weston and Adams, 1927-1929)([20]) or by the use of other optical aids (Weston, 1949)([21]).

There is ordinarily a very natural tendency to avoid, or restrict the severity of,

convergence fatigue by sufficiently frequent voluntary advancements of the gaze, which will set a limit to the rate of accomplishment of some kinds of work. Individually, the use of the eye muscles may be so nicely regulated that, although the kind of work and the kind of lighting seem calculated to tire the eyes, there is no complaint of visual fatigue. Because aversion to fatigue tends to " avoiding action," unless the incitement to work (motivation) is strong, no appreciable difference of " visual fatigue " among ordinary persons exposed to different grades of lighting might be demonstrable even if a reliable test were available. Ordinarily, a difference in output observed under different lighting systems may be taken to indicate a difference in fatigue. This is not, however, necessarily true; the difference may be due to a difference in the work/rest ratio, whereby the fatigue actually experienced under each lighting system is held constant. Even so, however, a difference in output implies that *but for it* there *would be* a difference in fatigue.

Fatigue of muscles can only be regulated " voluntarily " up to a certain point; by the " wisdom of the body " it is not allowed to go too far. Muscles are excited (though not supplied with energy) by impulses propagated to them along their motor nerves, and it has long been known that " fatigue " occurs in the neuromuscular synapses (junctions) before the contractile power of the muscle fibres is exhausted. By " fatigue " in this context is meant a failure to transmit excitation from nerve to muscle, which is virtually equivalent to the failure occurring when a fuse blows between an electrical conductor and a solonoid or motor. Modern research has indicated that impulses arriving at the motor nerve endings cause the rapid liberation of minute quantities of a natural substance (acetylcholine) which stimulate the muscle fibres. There is much evidence that this substance is the essential agent of excitatory transmission at the voluntary neuromuscular synapses, and good reason for believing that it serves the same purpose at nerve junctions also (Dale, 1951) ([22]). Each dose released of this chemical stimulant is rapidly destroyed by another substance (cholinesterase) known to be concentrated at the motor nerve endings, and its action can also be suppressed by the presence of toxic substances. The physiological limitation of muscular fatigue may, therefore, be due, as in an older concept, to the local accumulation of " waste products " of muscle activity, or it may be due to an increased production of the anti-stimulant substance, or to a local exhaustion of the supply of the excitatory transmission agent itself. But the first line of defence against excessive muscular fatigue is in the central nervous system, at the neuro-junctions where the motor nerve cells await excitation.

The second form of ocular fatigue is that of the ciliary muscles, whose action accommodates the lens for vision at different distances. In normal (emmetropic) eyes no effort of accommodation is required for seeing remote things, and very little is needed for viewing objects at arm's length. When, therefore, the situation precludes a close approach to the objects of interest then, however these and their surroundings are lighted, fatigue cannot be due to excessive accommodation. If, however, the lighting sufficiently degrades the contrasts in the scene surveyed, or (by veiling glare) in the retinal representation of it, accommodative effort may be made to obtain more distinct vision. Being ineffectual, it is doubtful if such efforts are persistent, but what does continue is dissatisfaction with the sensory data collected by the eyes, and mental effort in deciding what they represent; there is strain in forming a clear picture in the mind from a blurred picture in the eye.

True accommodative fatigue, like fatigue of convergence, is due to excessively close work. Lighting is therefore responsible for this fatigue if it is such that it depresses visual acuity, and thus rules out a more reasonable viewing distance because the eyes could not resolve the smaller images they would then receive. Accommodative fatigue is possible in the one-eyed, but when it occurs from binocular close vision it is

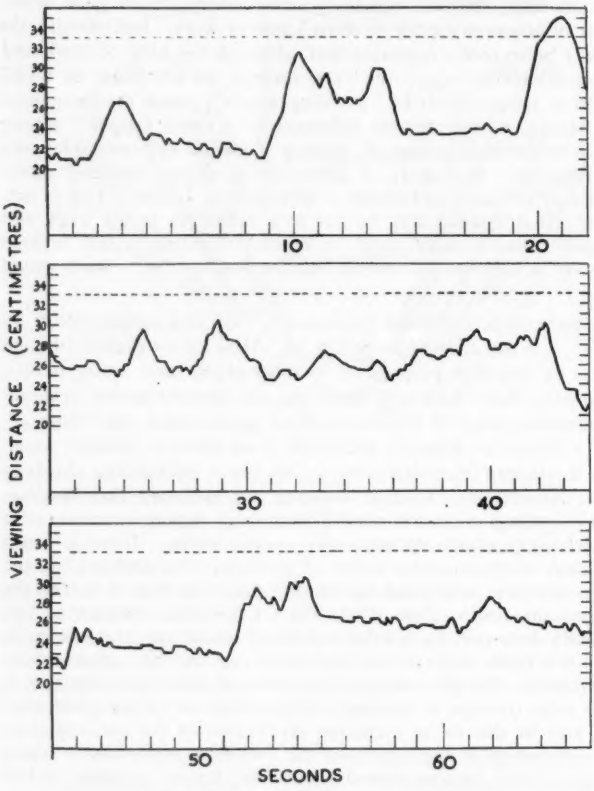

Fig. 2. Typical variation of viewing distance and therefore of amount of accommodation and convergence of the eyes, during "close work." Task: tracing. Illumination about 10lm/ft². Broken line corresponds to ordinary reading distance, or accommodation of 3 dioptres.

accompanied by convergence fatigue, because accommodation and convergence are synergic. Its functional symptom is blurred vision of near objects.

Accommodation is never held constant for long periods in near work, but is frequently varied, within limits separated perhaps by about one dioptre, even during short periods when the casual observer may notice no change in the worker's viewing distance. This variation is shown by photographic records of which Fig. 2, showing the records of a tracer, is an example. Fatigue, when it occurs, is due to high average accommodation. Occasionally, persistence in near work will lead to a functional spasm of accommodation. The effect of this is to bring the far point of distinct vision closer to the eyes; that is to say, the condition is one of pseudo-myopia and there is blurred vision of distant objects.

Already it has been said that unsuitable lighting may raise the accommodative demand in near work by leaving untapped too much of the potential acuity of the eye. The unsuitable factor is commonly the illumination provided, but, since the advent of discharge lamps has made available a fairly wide range of composite lights, the possible influence of these different lights upon acuity and "visual fatigue" has been debated. Now the effective acuity, or capacity for discrimination of detail, depends not only on the prevailing brightnesses in the visual field but also on the definition of the retinal images, which it is the function of accommodation to perfect. With "white" or

polychromatic lights the retinal images are always fringed, because of the inherent chromatic aberration of the eye. Therefore it has been thought that monochromatic light might give the best acuity, and also that spectral mixtures of the kind derived from some discharge lamps might make accommodation difficult. There is, however, no convincing evidence that for equal brightnesses near-monochromatic light (excepting, perhaps, sodium) is superior to " white " light, and recent investigation (Solandt, White and Rosen, 1952)([23]) has failed to show any significant difference in visual acuity with a variety of illuminants, including fluorescent light, all of which were sensationally " white."

Not only this, but the recent work of Fincham (1951)([24]) on the accommodation reflex and its stimulus has shown that, so far from the chromatic aberration of the eye being the defect it has been supposed to be, the different colour fringing which it gives to out-of-focus images according to the vergence of the light at the retina, provides a directional accommodation stimulus. That is to say, it " tells " a reflex sensori-motor mechanism which way to make the fine adjustment of accommodation—whether a little more or a little less curvature of the lens should be brought about. Although the rough adjustment of accommodation is normally induced by the act of convergence, the connection between the convergence and the accommodation mechanisms is too elastic to provide for precise accommodation; there is, of course, no control by convergence of monocular accommodation. There is another way—not yet fully elucidated—by which the vergence of the light at the retina stimulates the fine accommodation reflex. Fincham has suggested that, owing to the Stiles-Crawford effect, a difference of brightness between the two sides of an out-of-focus image may exist if the eye makes small oscillating movements while viewing an object, as his subjects were seen to do. The brighter side would then be right or left according as the light at the image is convergent or divergent. By some such means the accommodation reflex may be stimulated in monochromatic light, but Fincham found that 50 per cent. of people need, in addition, the stimulus which chromatic aberration affords in light of suitable spectral distribution. He has since found by experiment that fluorescent light provides this stimulus just as well as tungsten light.

General fatigue increases the inertia of accommodation and the difficulty of maintaining convergence. On this, and other accounts, it increases the " subjectivity in the eye," so that visual fatigue may be complained of rather than the true state of general tiredness.

(6) Eyestrain

The two varieties of ocular neuro-muscular fatigue that have been considered are especially liable to occur in persons who have some uncorrected error of refraction, or some latent imbalance of the extra-ocular muscles (heterophoria), because abnormal neuro-muscular action is then required for good vision. The enhanced liability to fatigue due to such anomalies is the " weakness of sight " which is meant by the term " asthenopia." A too easily fatigued muscular system of accommodation, or, rather, one that has constantly to do more than its proper share of work—as in compensating for long-sightedness—is said to be the basis of what is called " accommodative asthenopia." Correspondingly, a muscular system of convergence that has the extra task of overcoming a tendency to squint is the basis of what is called " muscular asthenopia," or " asthenovergence " (Stutterheim, 1937)([25]). Both varieties of asthenopia are frequently referred to as " eyestrain " but, because these anomalies sometimes exist without producing any symptoms, because there is no definite relationship between the severity of the symptoms when they do occur and the degree of refractive error or the muscle imbalance, and because the wrong glasses may cure some complainants of eyestrain and the right glasses may not, it has been held (Inman, 1924)([26]) that eyestrain is often an expression of emotional disturbance and is due more to a psycho-neurotic disposition than to the action of the muscles governing accommodation and binocular

vision. It is at least safe to say that emotional stresses and instability often decrease the tolerance of discomforts and fatigues. Moreover, there is no doubt that complaints of eyestrain or visual fatigue—whether the eyes, the work, or the lighting be held at fault—do come frequently from people who are highly strung, sensitive or of nervous temperament. A feeling of eyestrain can, of course, arise in normal sighted (approximately emmetropic and orthophoric) persons in the most blameless lighting if the task is such that the motor apparatus of vision has to be driven nearly "all out" for sufficient time. It can also arise from immobilisation or restricted activity of the ocular muscles, as in prolonged concentration of the gaze or scanning of a small angle field, even if the field is not a near one and if its contents are plainly visible ("postural eyestrain," Weston, 1949)[27].

(7) Other Muscles Involved in Vision

Only part of the total muscular activity subserving vision goes to the adjustment of accommodation and convergence. Ignoring the pupilliary muscles, which are not voluntarily controlled, the extra-ocular muscles are used for every movement of the eyes over the scene, as well as for keeping the eyes in particular postures when the visual occupation so demands. The eyelids must be kept open—sometimes by an effort strong enough to overcome the blink-reflex—and some of the facial muscles, shown in Fig. 3, as well as those of the neck, are involved as accessories in conative vision.

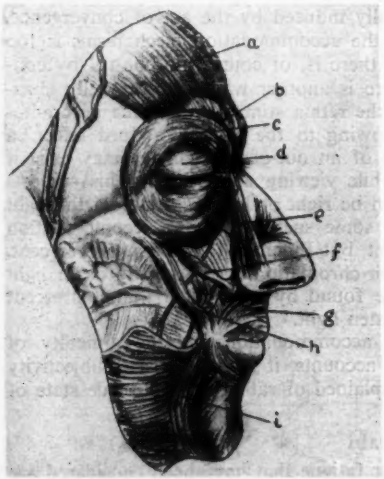

Fig. 3. Some facial muscles active in vision. a, Frontalis ; b, Corrugator ; c-d, Orbital and Palpebral Orbicularis ; e, Levator labii sup. nasi ; f, Zygomaticus minor ; g, Orbicularis oris ; h, Zygomaticus major ; i, Depressor anguli oris.

Indeed, since critical vision is essentially an act of close attention, it can involve the whole voluntary neuro-muscular system of the body, largely by way of inhibition, or "freezing," of all movements which might mean failure of the eyes to gather all the sensory impressions the mind needs to facilitate fine visual discrimination. Despite—perhaps because of—familiarity with attention, its dynamic and wholesale character is often insufficiently appreciated. That motor control is involved of all the parts of the body that can be voluntarily controlled is obvious enough in soldierly attention, and the word itself (from the Gr. ἀτενης) means "strained tight." Voluntary attention to visual, or any other, sensory presentations is more fatiguing and difficult to sustain the more complete it is made by motor-control, as well as by whatever intra-cerebral control there may be of the activity of sensory centres.

The diffuse fatigue that follows from the extensive bodily tenseness associated with intent vision can only be called "visual fatigue" if much of the whole organism is regarded as constituting the visual system—at any rate while voluntary attention is given only to vision. It is less open to misunderstanding, however, to speak of "fatigue occasioned by visual concentration." When such fatigue enters into consciousness as "feeling" on an occasion of dominantly visual activity it is understandable that association of the feeling specifically, and sometimes exclusively, with "the eyes" occurs in those who are not much given to analysis.

(8) The Posture of the Eyes and Head

The posture of the head necessitated by inadequate illumination of bench—or table-work—objects, and by the inspection of minute objects of this kind even if they are highly illuminated, has not escaped notice by those who have been most concerned about the hygiene of vision. In his early eighteenth-century treatise on the diseases of workers, Ramazzini[28]—the father of industrial medicine—laid stress on the evil effects to those who do fine work of keeping the head constantly bent and the eyes fixed with continuous muscular tension upon what they are doing. The nineteenth-century oculists Cohn[29], of Germany, and Priestley Smith[30], in England, who campaigned for better lighting and better desks in schools, drew attention to these causes of fatigue and believed—as Ramazzini did—that they were also among the causes of myopia.

In its natural position the head is erect and the plane of fixation of the eyes in the position of functional rest (the primary position) is horizontal, or nearly so. In almost every kind of work done at a bench, desk, table or machine, the work is below the standing or the seated eye height, so that the head is more or less inclined forward and the plane of fixation is no longer perpendicular to the frontal plane of the eyes, but is inclined downwards by exercise of the inferior recti and the superior oblique muscles. Coupled with the effort of convergence there is, therefore, the effort of maintaining the depression of the eyes, although the eye-muscles make looking down second only to looking straight ahead in point of ease. The possible angular excursion of the eyes in the downward direction is limited to about 50 deg. Photographic studies of a variety of workers show that they generally avoid depressing the eyes to more than about half this angle. If this is not sufficient to secure fixation of the work, bending of the neck and trunk takes place. The average downward rotation of the

Fig. 4. Involuntary change of head posture to limit angling of the eyes. Clerical work.

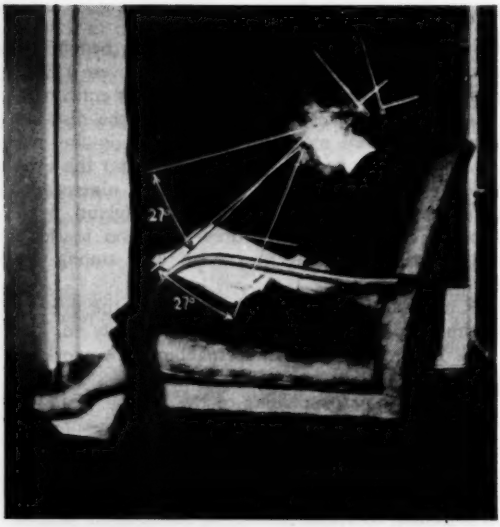

Fig. 5. Involuntary change of head posture to limit angling of the eyes. Reading.

eyes found for operators who do their work standing is about 27 deg.; for operators who work sitting the average eye depression is about 24 deg. Sometimes, owing to the location of the work, or to faulty habit of the worker, the downward angling of the eyes, instead of being limited to some 50 per cent. of the maximum, is as much as 70 per cent., and, occasionally, it is even more. Such an eye posture cannot be long sustained, and those who attempt it frequently complain of fatigue.

Fig. 4 shows a book-keeper at work while wearing a head attachment, which

Fig. 6 (Left). Posture of the head to avoid undue depression of the eyes in tailoring; note also the knitted brows.

Fig. 7 (Right). Posture of head and eyes when directing the gaze vertically downwards.

enables the vertical angling of the eyes to be measured from the photograph. Actually, two photographs have been superimposed to show how the eye and head depressions change when fixation is transferred from the top to the bottom of the page. The eye depression, which is nearly 60 per cent. of the anatomical limit when working on the top line, is prevented from exceeding this value very much at the bottom line by an increase of 25 deg. in the depression of the head. The total effort required by the work is thus distributed between the ocular muscles and the muscles of the neck and shoulders; it would be insupportable if required of the ocular muscles alone.

Fig. 5 shows the same person engaged in reading. Here there is greater freedom in choice of posture, and the smaller depression of the eyes is kept constant as the gaze travels from top to bottom of the page. To limit the eye depression to 27 deg., the inclination of the head varies through an angle of 22 deg. as the page is read.

In Fig. 6, although the depression of the tailor's eyes cannot be measured, it is evidently greater than the book-keeper's, owing to the position of the work. Evidently, too, the corrugator muscles are being used, as well as each orbicularis, to aid in keeping the eyes depressed, and the exertion of these muscles, as well as those of the neck, contributes to such fatigue as the work entails.

Fig. 7 shows a worker whose plane of fixation is turned downwards through 90 deg. from the normal. But only 23 deg. of this depression is achieved by a cardinal rotation of the eyes from the primary to a secondary position, the remaining 67 deg. being due to bending of the neck to the fullest extent, and to bending the trunk above the mid-dorsal region. This extreme measure to limit the fatigue of

Fig. 8. Arrangement of machine and operator's seat to place the work at eye level. Hosiery linking.

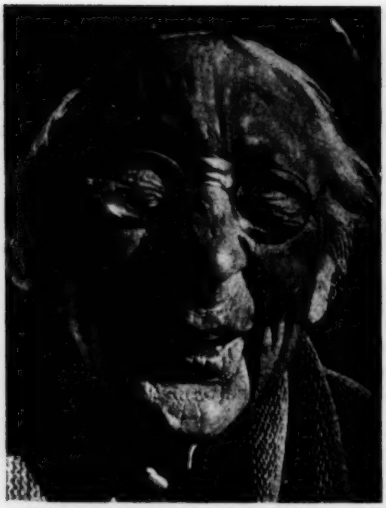

Fig. 9 (Left). A striking illustration of the expression—and permanent wrinkling—produced by contraction of the facial muscles for intent vision in very bright surroundings.
Fig. 10 (Right). Expression due to contraction of the "grief muscles" on exposure to glaring photographic studio lights.

ocular depression is evidently thought to be worth while on the whole, but the posture is one likely to impede the ocular circulation and to favour the occurrence of some of the well-known symptoms of "tired eyes."

Quite different are the conditions for hosiery linkers (Fig. 8). Here the fixation point is only slightly below eye level when the worker's head is erect. There is no fatigue due to neck bending or eye depression, but the viewing distance is short, thus involving considerable accommodation and convergence.

(9) Voluntary Muscular Reaction to Glare

The muscles of the lids—the levator and the orbicularis—the corrugators, the occipito-frontalis, and sometimes the muscles of the cheek and upper lip, are associated with vision—either habitually or under particular conditions of field brightness. Darwin's well-known work on the expression of the emotions ([31]), contains an excellent account of his careful observations on the use of the facial muscles during intent vision, particularly in bright surroundings. He pointed out that, when striving to distinguish a distant object in broad daylight, it is the almost invariable practice to contract the brows to prevent the entrance of too much light, the lower eyelids, cheeks and the upper lip being raised at the same time to lessen the orifice of the eyes. These muscular contractures are strikingly exemplified in Fig. 9, which portrays a very old woman, so long accustomed to make them that they have permanently lined and furrowed her face. The feeling of strain in seeing is much augmented when the facial muscles have to be used in this manner.

Some of the muscles which act together to produce the obliquity and drawing together of the eyebrows, which is so characteristic a feature of the expression of grief, anxiety or distress, are known as the grief—or the trouble—muscles. As a rule they come into play involuntarily. Fig 10 shows them in action expressing the distress

Fig. 11 (Left). Typical expression due to action of the "grief muscles" when attempting detailed seeing in the presence of glaring lights.

Fig. 12 (Right). Another example of the expression of distress occasioned by glaring lights.

occasioned by the photographer's glaring lights, because the boy is *trying to see in detail* instead of gazing *without purpose* in the direction of the lights.

Other examples of the action of these muscles are shown in Figs. 11 and 12. The contribution these contractures make to the felt fatigue associated with seeing can hardly be called in question, and they are undoubtedly among the causes of frontal headache, which is often one of the symptoms of those who complain of eyestrain. (Parsons, 1910.) (32)

The conditions of lighting in which these photographs were taken would be considered intolerably glaring in an office or a factory, but it is important to recognise that the discomfort and fatigue they cause depends a good deal on what the seeing *mind* is trying to get from what confronts the eyes, or, in other words, upon the set visual task. Actors on the stage, and in the cinema and television studios, face blazing lights, but their visual task is not an exacting one—they have only to look in the direction of the audience, or the camera, without attempting to discern anything in particular—and they rarely show any signs of glare. Of course, even if they were distressed by the lights, their business demands that expression of their discomfort be inhibited, but it is probably true of actors in general that, because they make no mental effort to make out detail, they do not experience such discomfort and fatigue as others would in similar lighting. One artiste questioned by the author felt more comfortable when looking sourcewards rather than out of the spotlight beam. Here, the surrender to the *fixation reflex*—which is actually desirable—avoids the voluntary effort required to over-ride it; this effort is a chief source of the fatigue which others often experience in the presence of glare sources.

The effect of varying the visual task on the expression of effort and distress caused by glaring lighting is shown by Figs. 13 and 14. In Fig. 15 the subject is evidently less distressed by glare than were the subjects of the preceding photographs. He has

Fig. 13. The expression accompanying intent visual inspection in the presence of a severe glare source (left) contrasted (right) with the expression in the same presence during "casual seeing."

Fig. 15. A subject showing little glare distress. Lighting as for Figs. 13 and 14. Left, critical vision; Right, casual seeing.

somewhat narrowed the eye apertures and has the expression of intentness while discriminating, but not of distressful effort—there are no vertical furrows between the brows.

All subjects were exposed to the same lighting conditions. A 250-watt photoflood lamp in a 10-in. diameter silvered reflector was set about four feet away. The fixation

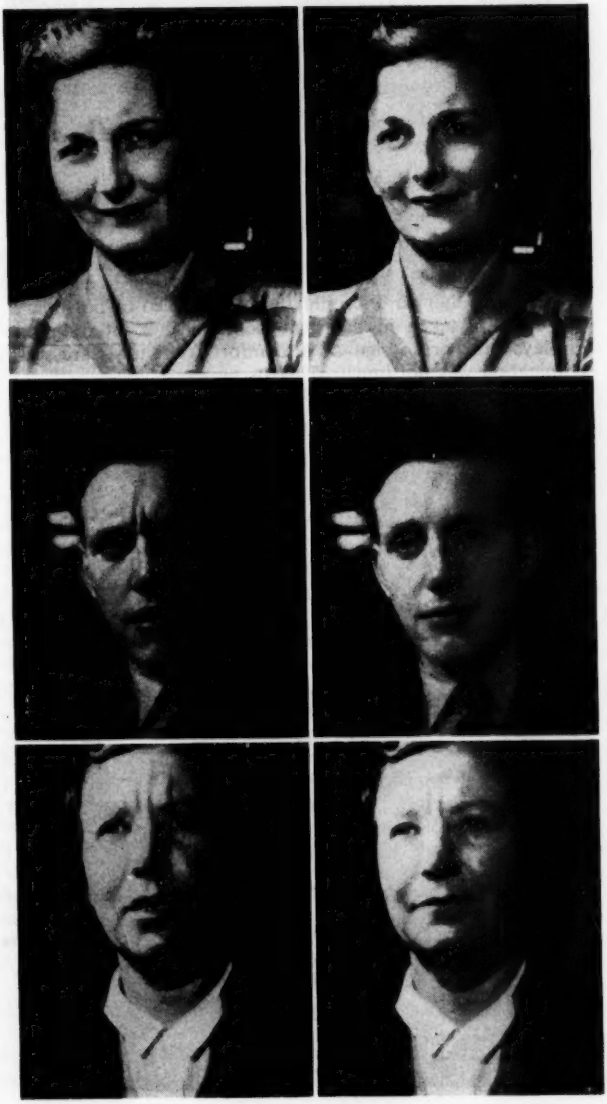

Fig. 14. Further examples expressive of the different mental states and muscular exertions excited by bright lights according to the nature o the visual task. Left critical seeing; Right, casual seeing.

Fig. 16. A subject showing no glare distress either in critical or casual seeing. Lighting as for Fig. 15.

point was about 9 deg. below the centre of the glare source. The subject first looked at a patterned field and was asked to distinguish its details; then a blank field was presented so that no discrimination was needed or possible.

Fig. 16, taken in the same conditions, is interesting as showing a person who displays little or so sign of discomfort from the glare source, and whose visual discrimination was not impaired by its presence.

Fig. 17. The frown shown here is indicative of difficulty in seeing the thread and needle owing to the tailor's inability to focus the eyes for nearer vision.

Fig. 18 (Left). In persons blind from birth frowning is unserviceable and usually does not occur when the subject is intently occupied.
Fig. 19 (Right). Another illustration of the passivity in the blind of the facial muscles usually associated with vision.

(10) Frowning

The simple frown so often associated with attentive vision is due chiefly to the action of the corrugators unopposed by the action of the central portion of the frontalis muscle. The frown can be seen in Fig. 17 and, in this example, it is expressive of the difficulty in seeing to thread the needle on account of the tailor's presbyopia. Contraction of the corrugators also assists in keeping the eyes depressed—as contraction of the frontalis assists in keeping them elevated—which explains why the tailor shown earlier in Fig. 6 is frowning although his presbyopia is corrected. Persons blind from birth have practically no voluntary control of the corrugators, so that, as shown by Figs. 18 and 19, they usually do not frown when the mind is intently occupied, though *blinded* persons, as Fig. 20 shows, may continue to do so by force of habit, although it no longer serves its original purpose.

Darwin pointed out that there is an analogy, as far as the state of the mind is concerned, between intently scrutinising some object and pursuing an obscure train of thought, and the habit of frowning which is practised as an aid to the one activity is carried over to the other for which it is not needed. Frowning is not, therefore, necessarily indicative of any real difficulty in seeing even when it occurs while a person is engaged in some visual occupation. It may occur when the lighting of the work is good as well as when it is bad, either from habit or because the work is troublesome to the mind aside from its visual aspects. On this account, measurements of forehead muscle action potentials may be unreliable for the purpose of detecting the effect of different systems of lighting on the effort required for visual tasks, though some investigators have tried this method.

(11) Elevation of the Eyes

It is well known that to maintain elevation of the eyes is more rapidly tiring than to keep them depressed. To do this, the levator, the superior part of the orbicularis, and, sometimes, the frontalis are in action, in addition to the oculo-motor muscles. It is this posture of the eyes, more than the brightnesses in the visual field, that accounts

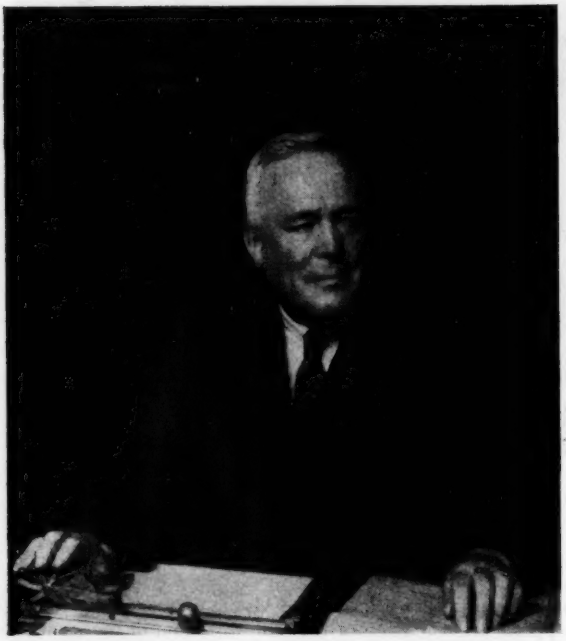

Fig. 20. The association of frowning with seeing is shown here by the persistence of the habit in mild form in this blinded man.

for the eyestrain and tiredness often experienced by people who occupy the front seats in cinema theatres: and it is for this reason that these seats must, by regulation* be sufficiently distant from the screen to render extreme elevation of the eyes unnecessary. Fatigue of the eye elevating muscles has also been held to be one of the causes of miners' nystagmus, and the oscillation of the eyes from which this complex condition gets its name is most readily elicited when the sufferer elevates the eyes. Especially in near vision, the effort to maintain convergence is considerably greater when the eyes are elevated than when the visual axes are in the horizontal plane or are inclined downwards. Hypnotists have often taken advantage of the fact that fixation with the eyes elevated is quickly tiring to the visual muscles, and, by leading to closure of the lids and exclusion of visual stimuli, facilitates induction of the hypnotic state. A tendency to sleepiness, or the relaxing wandering of the gaze, in schoolchildren who are called upon to sustain an upward gaze at chalkboard, wall-diagrams or the teacher, is partly due to this fatiguing eye posture. Obviously the postural factor cannot be eliminated by lighting.

(12) Visual Boredom

Different brightness distributions and different general levels of field brightness, besides affecting visual discrimination and the feeling of effort or of ease of seeing, are sometimes said to be soporific. Consider first an objective field of low average brightness. The effect of this is to narrow the field of consciousness by almost obliterating or greatly subduing much of the detail that otherwise would provide variety of visual stimulation. But variety is more than the spice of life; it is the *sine qua non* of

* The Regulations made by the London County Council in this matter are based on the recommendations of the I.E.S. Committee on Eyestrain in Cinemas, published in 1920(33).

conscious life. When sleep is desired it is wooed by excluding, or attenuating, as many sensory stimulants as possible. So, when there is no particular visual activity to perform, e.g., when listening to a sermon or lecture, the "dim religious light" often supposed to be adequate for the purpose favours sleep, and is said to be soporific. But sleepiness then is not due to fatigue but to subdued visual activity, as well, perhaps, as to ennui induced by a droning speaker. The effect is quite different when the need for visual discrimination is strong. Then, the dim lighting is frustrating, the mental effort of cognition is considerable and wearing, and there may be acute consciousness of the muscular effort involved in the necessary adjustments of the eyes. This is exemplified in night-driving without adequate lighting. So the same lighting can induce sleepiness or fatigue—which are different states—according to circumstances.

Indirect lighting is also said by some people to be soporific. Now the special feature of this lighting, when installed generally, is approximate uniformity of illumination over the "working plane" and softness of shadows. If it is used in an interior with pale-coloured walls, the brightness of the environment may be monotonously even and boring. Boredom is not fatigue—it more resembles adaptation. It is a state of disinterestedness, characterised by inattention and by a feeling of weariness quite different from the feeling of fatigue due to muscular and mental exertion. If unrelieved it induces sleep. In visual boredom there is no diminution of functional capacity, only a feeling of being "tired (or sick) of the sight of." Now, as Adrian (1947) has remarked in discussing the alpha rhythm of the brain, which is associated with the inattentive state, "It is difficult for us to be quite inattentive to what is before our eyes . . . but it can be made easier by looking at a uniform screen with nothing on it to catch the eye." Yet some exponents of what it is fashionable to call "brightness engineering" have suggested that ideal seeing conditions exist when there is substantially a uniformly bright visual field. This suggestion is insupportable on psychological grounds.

Even when there is a sufficient brightness diversity in an artificially lighted interior to prevent rapid visual boredom, there is one inherent feature of modern lighting that seems less desirable than it is usually assumed to be. This is its constancy—a feature which has so often been extolled and said to give artificial lighting some superiority over fickle natural lighting. But, however desirable constancy may be for critical visual tasks, it is a deadening feature of general artificial lighting. Whatever the brightness ratios may be within the objective visual field, they never change. Look anywhere and, time after time, what is seen has on each occasion its own unvarying brightnesses—absolute and relative—which become "familiar even to boredom." But daylighting is "alive": not only the absolute brightnesses but their ratios change, and the changes gratify the craving for variety which is fundamental to vision and all the senses. The achievement of "ideal" static brightness ratios will not bring artificial lighting to life; what is needed—however impracticable it now may be outside the theatrical field—is some method of making artificial lighting suitably variable though constantly adequate. Perhaps in no other way will continuous artificial lighting be made as universally endurable without complaint as daylighting is.

(13) Distracting and Confusing Brightnesses

Any conditions of lighting which tend to distract the gaze from whatever should be its object are likely to cause annoyance and to intensify the feeling of effort or strain in maintaining attention to the necessary visual task. The most familiar distracting condition is the presence of bright light sources which are sufficiently intrusive in the peripheral field to call for inhibition of reflex phototropic movements of the eyes. An extreme example is the headlight of an approaching car at night. The effort required of anyone driving in the opposite direction to keep the gaze away from

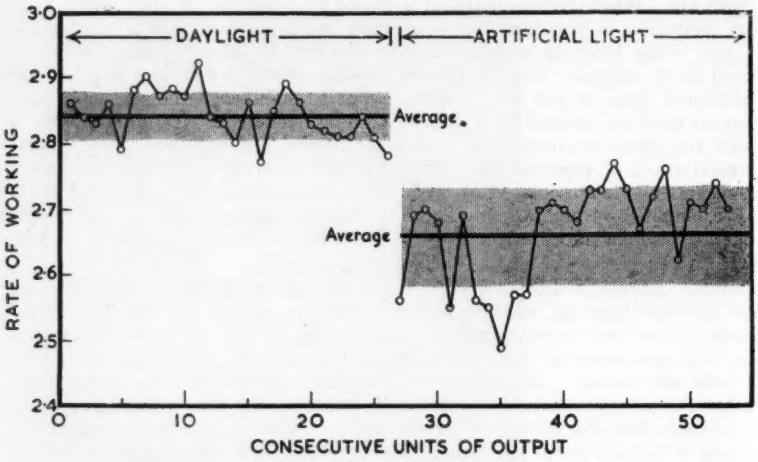

Fig. 21. Graph showing the deterioration of performance of inspection of cartridge cases due to dazzle from the work-objects in unsuitable artificial lighting.

the blinding light, and to the near side of the road, is considerable, and it is undoubtedly muscularly and mentally fatiguing. In this example, the effect of the bright light is quite different from its effect in the theatrical example, because the vehicle driver has a critical visual task to do.

Visibly flickering light sources also cause fatigue, partly for the same reason, and partly because periodic fluctuations of illumination due to such sources may cause visual confusion and difficulty in maintaining fixation. It is well known that the use of unsuitable, or unsuitably placed, light sources for work involving inspection of shiny objects may cause persons to be dazzled by their work objects. If dazzling occurs the work is described by those who do it as "more difficult" and "fatiguing." Fig. 21 illustrates this (Wyatt and Langdon, 1932)(34); due to dazzling by polished brass cartridge cases, the time per unit of output became more variable than in diffuse natural lighting, and the average rate of output fell by about 7 per cent.

(14) Self-control of Fatigue

Finally, the tendency to ration "felt ocular fatigue" in visual occupations may be illustrated by Fig. 22, which is based on a time study of several "fine" operations. Here the periods of intent and very close vision are followed by periods of ordinary vision, and these are succeeded by periods of casual and distant vision. The duration of each of these periods is different for each operation performed, though the duration of each phase of the respective seeing-cycles is usually similarly proportioned. Usually not more than half of the cycle-duration is spent in fatigue-inducing vision. These studies refer to good lighting. Under adverse conditions more of the visual activity may be unproductive, or more productive of mistakes, but there may be no greater total expenditure of energy than there is under conditions of lighting which allow this energy to be expended more productively. Most people energise at their maximum only occasionally and, as has already been stated, under strong motivation. Habitually, they work well within their physiological capacity and, by taking suitable "rest-pauses"—either spontaneously, whenever a feeling of fatigue arises, or involuntarily—they avoid undue fatigue. This is just as true of working with the eyes as with other

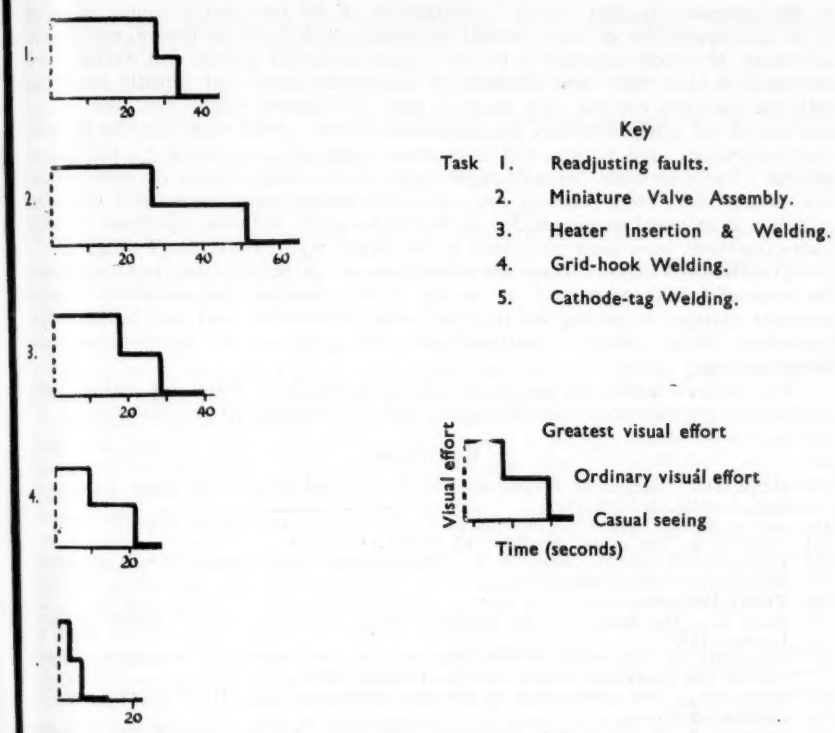

Fig. 22. Diagram representing the time-distribution of visual effort in five industrial operations.

workable parts of the body. Because neuro-muscular fatigue of the ocular apparatus is *usually* not allowed to become cumulative during ordinary spells of visual work, attempts to demonstrate it by seemingly appropriate tests, applied before and after the work, have generally failed. Unmistakably bad conditions of lighting and "forced labour" of the eyes, e.g., determined vigilance and unphysiological posturing (including keeping the eyes too close to the work), are required to induce it prematurely in persons who have no optical or neuro-muscular defect. By prematurely is meant sooner than it occurs as part of the general fatigue of the system which is a normal feature of the diurnal rhythm of life.

It is noteworthy that many of the complaints that one or other particular system of artificial lighting is "tiring to the eyes" are made when the day is well advanced; but it is just then that artificial lighting is most prevalent, so that it is most exposed to risk of criticism by people who are already physically and mentally tired to some extent.

(15) Conclusion

Summing up, "visual fatigue" may be defined in terms of the ordinary conception of fatigue as "weariness resulting from the bodily and mental exertion of seeing." The nature of mental exertion is obscure, and in the present state of ignorance about

it, the expression is used simply in recognition of the fact that a feeling of effort is an accompaniment of some mental processes which have no known motor concomitants. The bodily exertion is that of a neuro-muscular system, and consideration has made it clear that those elements of this system which are directly associated with the eyes are not the only ones at work in attentive vision. In such vision, exertion of the whole voluntary neuro-muscular system of the body may be involved and, accordingly, the fatigue that may ensue—although occasioned by looking—is general. The expression "visual fatigue" may not be worth having on these terms: but, in any case, more precisely descriptive expressions ought to be used whenever reference is intended to fatigue due to the discharge of particular functions. Some such expressions have been mentioned in this paper, e.g., "convergence fatigue."

Conditions of lighting which are sub-optimal for particular visual tasks accelerate the onset of fatigue occasioned by seeing, chiefly because they necessitate undue muscular exertion in getting the required visual information, but also because they necessitate undue mental "exertion" for the processes of interpretation and discrimination.

The author's thanks are due to his colleague, Mr. E. J. Ward, for making most of the photographic records for this paper, and for preparing all the illustrations.

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Discussion

DR. J. W. T. WALSH: I think we all agree that this is a difficult paper to discuss because the subject itself is both difficult and complicated.

Probably one of the most useful things that we can do about it is to get into people's heads that what they call "visual fatigue" is not specifically associated with the actual visual process, because I am quite sure that 95 to 99 per cent. of the population, when speaking of visual fatigue, think of something going on in the eyeball which makes the process of vision more difficult. I remember when I was young I was told not to read in a bad light because it would strain my eyes and that it was bad to read in the train for the same reason. I am sure it is this sort of idea which the man in the street has when he refers to visual fatigue under some particular conditions of illumination, and I believe that if we can get people away from it we shall be doing a really useful piece of work in the promotion of good lighting.

The illuminating engineer will want to draw something practical out of the paper and discussion, and in reading Mr. Weston's paper I tried to think of something which I could suggest. It seems to me that one thing which does emerge immediately is the fact that the more difficult the conditions for seeing, the greater the fatigue that will be experienced. Therefore, if the illuminating engineer can make seeing conditions more easy he will reduce visual fatigue. Various series of experiments have indicated quite clearly the way in which good lighting will improve such things as visual acuity or the ability to see small contrasts. These are matters of experiment and I think, therefore, that we can justifiably conclude that good lighting must reduce fatigue which is the result of carrying out any particular visual task because the visual task depends upon the various factors I have mentioned.

Of course, someone will be sure to say that he would feel happier if he could have some measure of visual fatigue. Given two systems of lighting, he would like to be able to say that with the one system the fatigue involved in carrying out a particular task was so much and with the other system it was so much, either less or more. I think we shall all have to agree that any such clear-cut measure of fatigue is probably not to be hoped for. The same thing applies to sensation. You cannot measure sensation. On the other hand you can say when two sensations produced by two different brightnesses are equal. To that extent you have a criterion of quality and I would like to ask Mr. Weston his reaction to the idea that, as a result of experimental work, we may one day have some means of telling when a particular level of fatigue is reached as the result of carrying out a particular task under particular conditions of lighting. If this were possible we might not be able to say that one system of lighting was half as fatiguing as another, but we could say it was more or less fatiguing, and perhaps adjust the conditions until the fatigue result was the same for both systems.

Mr. Weston makes a remark referring to the use of output as a measure of fatigue.

He says that a difference in output implies that but for a difference in the work/rest ratio there would be a difference in fatigue. This seems to indicate the possibility that a criterion such as I have referred to might be found in the measure of output, but I think Mr. Weston would be the first to agree that measuring output can be very misleading as a measure of fatigue because it is affected by so many other conditions. However, I do not think we should give up hope altogether. We should start by studying some of the tests—such as those with which Mr. Weston has been associated over a number of years—and we should endeavour to arrive at something which will help the illuminating engineer to get some more or less concrete way of determining whether one particular situation is more fatiguing than another or whether it is not. I think all we can do in the meantime is to say that anything which improves the performance of the eye in any particular respect must necessarily reduce fatigue when carrying out a task in which that particular function of the eye is involved.

MR. J. B. COLLINS: Mr. Weston has very carefully emphasised the distinction between fatigue of the neuro-muscular apparatus of seeing and the nervous or mental fatigue which may be visually occasioned and I should like to ask him whether we, as lighting engineers, can conclude from this paper that provided we avoid the grosser errors of bad lighting practice—such as providing obviously inadequate illumination or glaring sources in the field of view—the avoidance of strain of the visual apparatus is really the responsibility of the motion study experts. So much depends on the actual posture and conditions of working that it may be that it is these people who should relieve muscular strain rather than lighting engineers.

On the other hand Mr. Weston has led us to the brink of the little known world of the operation of the mental processes, and I should like to know if he thinks that those who are anxious to know the effects of the more subtle differences between adequate lighting installations in affecting what may be called " mental fatigue—visually occasioned," after say a long spell of difficult visual work, will have to turn their hopes to work now being planned with the aid of the psychologists. Information already obtained seems to indicate that it is possible to evaluate a reduction in alertness as a result of general fatigue from non-muscular causes, and if such evaluations could be made sufficiently sensitive to show changes due to the effects of working under different types of lighting, then I think we should make a very great step forward.

MR. R. R. HOLMES: I should like to ask whether the use of a support or rest for the head or the hand by those engaged in fine tasks would help the subject to work at an optimum visual distance without having to hold the body in the right position. When using a magnifying glass you will find that the breath has to be held to keep the distance correct during the most critical period of the task, and a light rest might relieve one of that function: it would not necessarily fix the position. I knew of one particular industrial process in which a rotating component had to be critically viewed; they were gazing at the side of the task rotating towards the worker and had obvious difficulty in focusing. It was explained that if they gazed at the front of the task vision would be much easier but no attempt was made to change the position because a new head rest would be needed, and recently when I went round this works I found that this necessary change had not yet been made.

Mr. Weston mentioned the actress who said that she preferred to look into the lights. I can assure you from experience that it is more common for the actor to wish to be in the light rather than to look into it, because he knows that if he can see the source of the light out of the corner of his eye then every expression will be effective. There may be something in being in the light and not looking into it.

MR. J. G. HOLMES: Mr. Weston has repeated one of the points which was

emphasised by our President last October when he said that it is very rare for the retina itself to show signs of fatigue of a physiological nature, due either to brightness or to contrast. It follows that any visual fatigue which occurs due to brightness or to contrast must be largely nervous in origin and that our complaints about glare must be related to the nervous fatigue which it causes. For this reason, the paper by Hopkinson and Petherbridge three years ago was a most valuable study of the subjective effects of glare because it is immediately obvious that the conditions of glare which they regard as "intolerable" must cause fatigue. In this sense, discomfort glare may lead to the same results in reduced visual power as disability glare. With disability glare there is an immediate reduction in the ability to see even in spite of added concentration; with discomfort glare there is a delayed reduction in the ability to see, due to fatigue, which can be overcome by added concentration, but this, in turn, leads to added fatigue. I wonder, therefore, whether Mr. Weston has any quantitative evidence that he can show to us on the degrees of glare which may lead to fatigue. I think it likely that the recommendations in the I.E.S. Code are confirmed by his experience, but these have been of a rather general nature and have taken no account of the "brightness grading" which was discussed and demonstrated by Hopkinson and Petherbridge. During the past year or so I have become convinced that discomfort glare is caused more by contrast between the glare source and its immediate surround than by the actual luminance of the glare source in candelas per square inch or any other unit. An example of this is given by the fluorescent tubular lamp which can be either exposed, or backed by a reflector of reasonable brightness, or shielded by diffusing material. The exposed lamp is not of high luminance, something less than 5 candelas per sq. in., but it is common experience that it leads to severe discomfort unless it is well removed from the line of sight. The bad habit in some shops of mounting a vertical fluorescent tubular lamp in a window is only an extreme example of what is commonly done in offices, works and all kinds of interiors. We have long got past the use of bare filament lamps or discharge lamps for general lighting, and I hope that we will soon get past the same stage in the use of fluorescent lamps. The glare from such lamps can be greatly reduced by the use of a reflector of reasonable proportions and shape, and even more reduced or entirely eliminated by the use of louvres and diffusing screens.

This is a matter of considerable importance to the lighting industry. I have said previously that in our efforts to provide adequate artificial lighting, we often confront the poor man in the street with extreme and inescapable glare which causes such discomfort as can only lead to fatigue and loss of visual performance. I should very much welcome Mr. Weston's comments on this matter.

MR. P. BALE: I am interested in this subject from the point of view of safety first on the roads. I find that after a tiring journey on indifferent roads, when I come into certain classes of lighting, such as sodium, it has almost a tonic effect on the tiredness of the eyes. On the other hand, when coming into mercury vapour lighting I find almost the reverse takes place. Is it my sight or is it fairly common to other people?

MR. S. S. BEGGS: I enjoyed Mr. Weston's paper, particularly as he translated the ophthalmological terms into common language, but I did feel that his interpretation of the term "visual fatigue" was not what I would have expected. He gives his interpretation in his conclusion as being the "sensation of weariness resulting from the exertion of seeing." I know that meaning is used in a general sense, for people do refer to eye-tiredness as visual fatigue, but from the technical point of view that would not have been my interpretation, and I would have agreed with the definition given at the end of Section (1), viz., "the decrease in the capacity for work." Thus visual effects, such as after-images, glare or blurring, possibly arising from marked or

repeated change of adaptation or accommodation, I would have classed as true "visual fatigue." I thought Mr. Weston rather ignored that side, and spent much time on what I would not have classed as true visual fatigue.

On the question of muscular fatigue of the body as a whole, this (as Mr. Weston suggests in Section (7) should be referred to as "fatigue occasioned by visual concentration," and I do not think it is fair to include all that as visual fatigue. If you go to a concert and have to turn round and listen hard and get rather stiff, you would not say you were suffering from "aural fatigue." On the other hand, if the bass drum made a loud noise which was followed by a quiet passage, heard with difficulty, I think you would say that was "aural fatigue." Similarly, I do not regard this body-tiredness as "visual fatigue."

So far as the muscles of the eye are concerned, again I would not have used the term "visual fatigue"; for this I prefer the term "ocular fatigue," which Mr. Weston used.

I got the impression from the photographs that the persons reading depressed their eyes downwards about 25 to 30 deg. from the normal to the frontal plane, whatever the angle below the horizontal to the point of regard; even when reading the top of the page they tended to face nearly horizontal and depress their eyes rather than bend the head and look more nearly straight ahead. Is this a preferred angle of depression of the eyes? I would be interested to know also whether there is some corresponding degree of elevation of the eyes before the head is tilted back.

MR. G. F. W. CLARKE: I can sit in an armchair and read a novel for an entire evening and suffer very little effect on the eyes, but if I take a difficult treatise, perhaps with mathematics in it, within about an hour and a half of study the eyes are extremely sore and irritated and so bad that the book is closed. I should like to know whether this form of fatigue is peculiar to myself and exactly how Mr. Weston would classify it.

DR. J. N. ALDINGTON: There are one or two special features about Mr. Weston's paper that made a particular appeal to me. It is one of those contributions which I personally will return to quite often because it contains so much of interest for both the physicist and the lighting engineer. Its publication in the "Transactions" in due course will add something to the stature of our literature.

I propose to mention only two reasons out of many to support this point of view. First of all there is the fact that Mr. Weston's paper contains so many simulating ideas. I will quote but one—"Daylighting is alive, not only the absolute brightness, but their ratios change, and the changes gratify the craving for variety." The author goes on to suggest that it may be difficult to achieve a simulation of this characteristic, but points out that the achievement of it might have certain advantages. It occurs to me that the suggestion is perhaps not so impractical after all even for certain classes of industrial work, and I personally intend to try something arising from that thought.

Secondly, I know that I shall often go back to re-read Mr. Weston's paper because of the beautiful felicity of expression which characterises not only this latest contribution but many of the other publications which Mr. Weston has given to the world and I am particularly thinking at the present time of his most helpful book "Sight, Light and Efficiency."

MR. R. W. GRAY: One thing that impressed me particularly in this paper, and which the last speaker emphasised, is the variation which would perhaps give us some relief from muscular fatigue where directly concerned with the nervous system or other parts of the body; the eye seems to crave for this variation which would give relief from some monotonous task. In Australia we have tried in industry to achieve this variation of brightness by the use of colours—I think to a greater extent than

in England. I would like to ask if such variations in brightness by the use of colour do help to relieve mental fatigue, or muscular fatigue, and also whether the use of some kind of dimmer system in an industrial plant by which the brightness can be varied in accordance with the colours, would also be of value.

MR. H. C. WESTON (in reply to the discussion): Dr. Walsh has pointed out that this is a difficult subject; it is indeed. As he said, if the illuminating engineer can make seeing conditions better, he will reduce fatigue. Suitable lighting can make a task more easily visible and at a more comfortable viewing distance, and, of course, the design of such suitable lighting is the illuminating engineer's function. Obviously there are other specialists who can co-operate to make various visual tasks as easy as possible; for instance, besides those concerned with optical aids, there are the motion study and job layout people who might do more to achieve arrangements of work which allow of easier eye movement and postures.

I deliberately avoided discussing the measurement of fatigue because that is an even more difficult subject and would require a separate paper. Quite a lot of work has been done to attempt to measure "visual fatigue," but most of it has been disappointing. All sorts of tests have been applied before and after particular visual tasks in the hope of getting some measure of fatigue, but no consistent results have been obtained. For example, it might be supposed that the balance of the extra-ocular muscles would deteriorate when prolonged close work is done, and that a change in muscle balance would be an index of fatigue, but this has not been found to be a reliable criterion. As mentioned in the paper, one of the reasons why so many of the attempts of this kind have proved disappointing is that people just do not ordinarily allow themselves to become much fatigued. It is not a question of deliberately avoiding fatigue so much as of doing so spontaneously. When we feel that "the eyes" are getting tired we relax a little, and we do this very frequently. Fig. 2 illustrates this point. "Vision" is very resistant to fatigue as distinguished from adaptation. It is easy to understand that this should be so; vision is so important to us that we might fare very badly if it were easily fatigued. Although I do not altogether despair of doing what Dr. Walsh suggested I think it is an exceedingly difficult thing to do. Many variables are involved, and one that must be controlled is the fatigue-producing task, but suitable test-tasks are generally boring and soon lead to fluctuations of attention; these prevent exercise of the ocular "working parts" in vision in such a way that any but a transient reduction of their functional capacity — elusive of measurement—is likely to occur.

Output is not a reliable guide for the reason that I pointed out in the paper. Output tends to be controlled in order to avoid distressful fatigue, and it is only when the "drive" is imperious that output is likely to be a good indication of the state of the worker.

Mr. Collins asked whether, if the illuminating engineer avoids the worst errors of lighting, the avoidance of strain in the performance of visual tasks does not pass to the province of the motion study people. To some extent it does, but occupations which are most likely to cause strain of the ocular muscles are inherently difficult and, apart from good lighting and rest pauses, sometimes the only thing to be done is to use optical aids in order to relieve the oculo-muscular effort required.

Concerning studies to which Mr. Collins refers as being planned with the aid of psychologists, while such aid is necessary—indeed studies of this kind properly lie in the province of experimental psychology—I confess I am rather pessimistic about the prospect of evaluating the effects of subtle differences between different systems of adequate lighting.

Mr. R. R. Holmes referred to a support for the head or the hand; would this ease the work? Sometimes it would; without recommending the contraption shown

during the lecture, devices could be used which would relieve the subject of postural strain in performing some visual tasks.

As regards looking into theatrical spot-lights, Mr. Holmes is no doubt right—it is necessary for the actor to make sure that he is in the light so that his facial expression can be seen. I think, however, that what I said is also true, and though I mentioned only one particular example, I am told by a well-known television announcer that she is not disturbed by exposure to similar bright lights—again because no visual discrimination is required.

Mr. J. G. Holmes considers that "nervous" fatigue due to brightness and contrast does undoubtedly occur, although I am uncertain what he means by "nervous fatigue." I suggested in the paper, Section (9), what I think gives rise to discomfort and fatigue on exposure to excessive brightness.

I can give no quantitative evidence relating glare to fatigue, and neither of these states is directly measurable.

While there is now no reference to brightness grading in the I.E.S. Code, I can assure Mr. Holmes that there will be when the next edition is produced.

Mr. Bale's experience of a restorative effect when encountering sodium street lighting after a tiring journey is interesting. I find this lighting stimulating myself. This effect is partly "psychological," but the actual brightness of the sodium lighted streets is probably greater than that of others. One's appearance is at least as bad with sodium as with mercury lighting, but the general impression received is more cheerfully toned.

Mr. Beggs's remarks underline my own at the outset of the paper, and I am not at all surprised that his conception of "visual fatigue" does not entirely coincide with mine. However, the definition I offered includes the one he prefers, since in popular parlance "weariness" refers not only to a feeling, but also to the underlying state of "enervation." Some of the phenomena Mr. Beggs would class as true "visual fatigue" are covered in Sections (4), (5), (6) and (9) of the paper. I do not regard after-images as fatigue phenomena. My thesis is that what is called "visual fatigue" is largely due to muscular activity in seeing, and that the innervations involved may go far beyond the strictly visual muscles. It is neither retinal nor any other purely "eye" fatigue.

As regards the angle of depression of the eyes, it does seem to be true that people frequently adopt an angle of about 20 deg. This is fairly comfortable, although it becomes fatiguing if maintained too long. If any greater depression of the gaze is necessary, then the neck is brought into play rather than turning the eyes down still further. I cannot give a figure for the comfortable limit of elevation of the eyes, but it is considerably less than the angle for depression.

Mr. Clarke asked why one read a novel without visual fatigue but not a difficult treatise. If the novel is an absorbing one we tend not to notice any feeling of fatigue, at any rate, until the reading is stopped. The difficult treatise, however, requires much more intent mental concentration as well as more exacting visual inspection. In reading a novel a great deal of "word-guessing" may be done, but a mathematical treatise has to be seen in detail.

Dr. Aldington said some very nice things, for which I thank him. I am very glad that he was interested by my rather extraordinary suggestion that perhaps we are not going on the right lines in striving for "ideal" static brightness ratios, but that we might try and bring artificial lighting to life by making these ratios variable.

In reply to Mr. Gray, I would say that while the use of colour to give pleasing variety to the visible environment of workers is desirable, and is gaining adherents in this country, it does not really meet the point I made.

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The following applicants have been duly elected by the Council to membership of the Society, and their names have been added to the list of members:—

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Printed by
ARGUS PRESS, LTD.,
Temple-avenue and
Tudor - street,
London, E.C.4,
England.